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RESEARCH MEMORANDUM

PERFORMANCE OF A MIXED-FLOW IMPELLER IN COMBINATION WITH A SEMIVANELESS DIFFUSER

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PERFORMANCE OF A MIXED-FLOW IMPELLER IN COMBINATION WITH A SEMIVANELESS DIFFUSER

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SUMMARY

The performance characteristics of a mixed-flow impeller and a semivaneless diffuser were experimentally investigated. The impeller has an annulus diameter of 11.00 inches and a maximum tip diameter of 14.74 inches. The semivaneless diffuser has an over-all diameter of 28.00 inches. The performance characteristics of the mixed-flow impeller were also investigated with a 34.00-inch vaneless diffuser having a transition section of the same geometry as the semivaneless diffuser. A comparison of the performance curves of the two combinations provided a means of determining how well the semivaneless diffuser was matched with the impeller.

The investigation of the mixed-flow impeller and the semivaneless diffuser was made over a range of equivalent impeller tip speeds of 682 to 1740 feet per second; tests of the impeller with the vaneless diffuser were confined to a range of equivalent tip speeds of 682 to 1546 feet per second with ambient inlet air.

The maximum adiabatic efficiency for the semivaneless-diffuser combination was 0.760 and was obtained at a pressure ratio of 1.34. The semivaneless-diffuser combination showed good retention of peak adiabatic efficiency to a pressure ratio of 3.35, where the efficiency was 0.702. Within the stable operating range, the maximum pressure ratio was 3.36, at which point the efficiency was 0.697 and the equivalent volume flow was 13,650 cubic feet per minute.

A critical condition existed in this combination between equivalent tip speeds of 1550 and 1644 feet per second. At 1644 feet per second, the stable-air-flow range was extremely limited and the peak adiabatic efficiency dropped sharply to 0.626 and the corresponding pressure ratio to 3.12. Mild surging was encountered at

all pressure ratios above 3.0 for the equivalent tip speed of 1740 feet per second; the peak efficiency was 0.580 and the corresponding pressure ratio was 3.36.

The semivaneless diffuser was found to be well matched with the impeller. The peak pressure ratios occurred at approximately equal values of volume flow for both diffuser combinations. At low tip speeds, the peak adiabatic efficiencies for both diffuser combinations occurred at approximately equal values of volume flow. At high tip speeds, the volume flows at which peak efficiencies were obtained differed for the two diffuser combinations but the difference in the values of the peak efficiencies was small.

INTRODUCTION

A combination of a mixed-flow impeller and a semivaneless diffuser designed primarily for a jet-propulsion engine was investigated at the NACA Cleveland laboratory. Tests were conducted to determine the range of tip speeds over which adequate adiabatic efficiency could be obtained and to determine whether the diffuser was matched with the impeller.

The impeller is suitable for a jet-propulsion engine installation because the configuration of the impeller is such that it discharges the air with an axial velocity component. Because of the shape of the impeller passage, the angular acceleration of the air is continuous along a radius; the angular velocity of the air, however, is always less than that of the impeller. This type of impeller develops a lower pressure ratio at a given impeller tip speed and inlet-air temperature but inherently has a larger stable-air-flow operating range than an impeller of the conventional radial type.

In the semivaneless diffuser, the large tangential velocity component of impeller discharge air is reduced to approximately seven-tenths of its original value in the vaneless section before reaching the vaned section of the diffuser. In comparison with a conventional vaned diffuser, the semivaneless diffuser permits the use of higher impeller tip speeds and air flows before shock is encountered at the entrance to the vanes. The semivaneless diffuser has a smaller diameter than a vaneless diffuser for a given amount of diffusion.

The performance characteristics of the mixed-flow impeller were also investigated with a 34.00-inch vaneless diffuser having a transition section of the same geometry as the semivaneless diffuser. Because the vaneless-diffuser combination has a flat performance curve, a comparison of the volume flows at peak efficiencies and pressure ratios for both diffuser combinations would indicate whether optimum performance of the semivaneless diffuser and the impeller occurred at the same flow rates and thus show how well the semivaneless diffuser was matched with the impeller.

Tests of the mixed-flow impeller in combination with both diffusers were made with ambient inlet air over a range of equivalent impeller tip speeds from 682 to 1550 feet per second. The tests with the semivaneless diffuser were extended to equivalent tip speeds of 1644 and 1740 feet per second with reduced inlet-air temperature. The results of the tests with the semivaneless- and vaneless-diffuser combinations are presented as curves of peak adiabatic efficiency as a function of pressure ratio. Adiabatic efficiency and pressure ratio are also plotted as a function of equivalent volume flow and the matching of the semivaneless diffuser with the impeller is evaluated.

IMPELLER AND DIFFUSERS

The mixed-flow impeller (fig. 1), which discharges the air with an axial velocity component, has 23 blades. Because of the shape of the impeller passage, the angular acceleration of the air is continuous along a radius; the angular velocity of the air, however, is always less than that of the impeller. Unlike the conventional centrifugal impeller, the blades do not have abruptly curved sections at the inlet section but are designed with a gradual curvature over the entire length. The tip diameter of the impeller decreases along the axial length from 14.74 to 14.26 inches. The impeller has an annulus diameter of 11.00 inches, an inlet hub diameter of 4.26 inches, and an axial depth of 7.26 inches.

The semivaneless diffuser consists of two sections: a vaneless section followed by a vaned section having 32 vanes. The diameter at the leading edge of the vanes is 20.67 inches; the over-all diameter is 28.00 inches. Figure 1 shows the semivaneless diffuser and the impeller with the impeller and diffuser front shroud removed. A few vanes are thicker than the others in order to facilitate mounting in an engine installation.

The vaneless diffuser has an over-all diameter of 34.00 inches. The curvature of the first few inches of the transition section is the same for both diffusers as shown by the cross-sectional sketch of the two diffusers superimposed (fig. 2). Unlike the semivaneless diffuser, which discharges the air in an axial direction, the vaneless diffuser discharges the air in a radial direction.

APPARATUS

Test rig. - The impeller with the semivaneless and the vaneless diffusers was tested in a variable-component test rig as described in reference 1. The complete test setup for ambient-air tests is shown in figure 3. The impeller was driven by a 1000-horsepower dynamometer in conjunction with a magnetic coupling and the speed was regulated with an electronic control system.

The entire inlet pipe was lagged with three 2-inch layers of hair felt; between each layer were tar and tar paper with a final covering of felt, paper, and canvas. The outlet pipes were lagged with a $1\frac{1}{4}$-inch layer that was 85 percent magnesia and were covered with canvas for a distance of 3 feet beyond the instrument station. The variable-component collector case was surrounded by an air space and a wooden box insulated within with three 1/2-inch layers of cane fibre.

Ambient air was metered through a large orifice tank and was passed through an inlet throttle into a pipe leading to the impeller inlet. The air was discharged through two tangential pipes from the large variable-component collector case to the atmospheric exhaust system.

Refrigerated-air tests required modification of the test rig (fig. 4). An additional speed increaser was installed to permit better control by the magnetic coupling at the high impeller tip speeds. A large air-filter tank was installed between the inlet throttle and the straight length of inlet pipe entering the test unit to collect any foreign particles that flaked off the refrigerated-air pipe during the tests. The filter tank was insulated with 6 inches of hair felt and covered with canvas.

Instrumentation. - The quantity of air flow through the unit for the ambient-air tests was measured with a sharp-edged circular flat-plate orifice connected to the orifice tank. The temperature of the air entering the orifice tank was measured with four calibrated iron-constantan thermocouples located in front of the tank. Refrigerated-air flow measurements were made with an adjustable submerged orifice. The air temperatures were measured with two calibrated iron-constantan thermocouples located in the pipe upstream of the orifice.

The inlet measuring station was located 2 diameters of straight pipe from the impeller inlet. The outlet measuring stations were preceded by 12 diameters of straight pipe. All measurements were made in accordance with the procedures described in reference 1.

All pressure and temperature measurements were taken in pairs to eliminate erroneous readings. Air pressures were indicated by mercury manometers; pressures for air-volume measurements were indicated by water manometers. All temperatures were measured with calibrated iron-constantan thermocouples.

The impeller tip speed was measured with an electric chronometric tachometer; the impeller tip speed was based on the maximum tip diameter of the impeller. For visual checks on the impeller tip speed during the tests, a stroboscopic tachometer with a 60-cycle neon light was used.

Precision. - The precision with which all measurements were made is estimated to be within the following limits:

Temperature, °F	±0.5
Pressure, inches of mercury	±0.02
Volume flow, percent	±0.5
Impeller tip speed, percent	±0.5

TEST PROCEDURE

The tests with both diffuser combinations were made with ambient inlet air over a range of equivalent impeller tip speeds of 682 to 1550 feet per second corrected to a standard NACA inlet-air temperature of 59° F. The inlet-air temperature varied from 74° to 98° F over the entire range of tip speeds made with ambient air. Tests with the semivaneless-diffuser combination were extended to equivalent impeller tip speeds of 1644 and 1740 feet per second by using refrigerated inlet air at temperatures of 31.6° and -21.1° F, respectively. The inlet-air temperature at any particular speed did not vary more than ±2° F.

The tests were conducted by the method given in reference 1 whenever applicable. In all tests the air flow was varied by the inlet throttle.

RESULTS AND DISCUSSION

Performance calculations were made by the method given in reference 2 and the results are presented as specified in reference 3. Additional performance curves of peak adiabatic efficiency as a function of pressure ratio are also presented. All impeller tip speeds and volume flows are equivalent values, having been corrected to standard conditions, as recommended in reference 3.

Performance. - The maximum adiabatic efficiency for the semivaneless diffuser combination was 0.760 and was obtained at a pressure ratio of 1.34 (fig. 5). Good retention of peak efficiency was obtained to a pressure ratio of 3.35, where the efficiency was 0.702.

The maximum pressure ratio of the semivaneless-diffuser combination was 3.36, at which point the volume flow was 13,650 cubic feet per minute (fig. 6(a)). The corresponding adiabatic efficiency was 0.697. At the lower tip speeds, the semivaneless-diffuser combination had a wide stable-air-flow operating range and a flat performance curve similar to that of the vaneless-diffuser combination (fig. 6(b)). Figure 6(a) shows that at a tip speed of 1353 feet per second, the stable-air-flow operating range of the semivaneless-diffuser combination abruptly decreased by approximately 67 percent. The range of air flows decreased as the tip speed increased and a vertical curve without any appreciable range was obtained at a tip speed of 1644 feet per second.

A critical condition existed in the combination between a tip speed of 1550 and 1644 feet per second. The peak adiabatic efficiency dropped to 0.626 and the corresponding pressure ratio to 3.12 (figs. 5 and 6(a)). At a tip speed of 1740 feet per second, the peak adiabatic efficiency decreased to 0.520 and the corresponding pressure ratio was 3.36, which was the same as that for the tip speed of 1550 feet per second. The critical condition still existed in the combination, however, and mild audible surging occurred at all pressure ratios above 3.0. At the lower values of volume flow for the tip speed of 1740 feet per second, the efficiency is not a unique function of pressure ratio and volume flow. Test points for this tip speed are therefore omitted in the region where two values of efficiency for a given pressure ratio and volume flow were obtained. The trend of the performance curve in this region is indicated by the broken line in figure 6(a) and the complete curves for the tip speed of 1740 feet per second are given in figure 7.

Matching. - A comparison of figures 6(a) and 6(b) shows that the peak pressure ratios for both diffuser combinations occurred at approximately equal values of volume flow, which indicates that, as far as obtaining peak pressure ratios is concerned, the semivaneless diffuser was well matched with the impeller. A representative comparison of the adiabatic efficiencies for both diffuser combinations was obtained by plotting adiabatic efficiency as a function of volume flow for several tip speeds (fig. 8). In general, the peak efficiencies for the semivaneless-diffuser combination were slightly lower than for the vaneless-diffuser combination. (See also fig. 5.) At the low tip speeds, the semivaneless diffuser was apparently well matched with the impeller. At the high tip speeds, the volume flows at which peak efficiencies were obtained differed for the two diffuser combinations but the difference in the values of the peak adiabatic efficiencies was small. With regard to efficiencies, the matching of the mixed-flow impeller with the semivaneless diffuser therefore appears to be very satisfactory.

SUMMARY OF RESULTS

From an investigation of the performance of a mixed-flow impeller and a semivaneless diffuser and from an evaluation of the matching of the semivaneless diffuser with the impeller (by a comparison with a vaneless-diffuser combination), the following results were obtained:

1. Good retention of high adiabatic efficiencies was obtained to a pressure ratio of 3.35, where the corresponding efficiency was 0.702. The maximum efficiency of 0.760 was obtained at a pressure ratio of 1.34.

2. Within the stable operating range, a maximum pressure ratio of 3.36 was obtained at which point the corresponding efficiency was 0.697 and the volume flow was 13,650 cubic feet per minute.

3. A critical condition existed in the unit between a tip speed of 1550 and 1644 feet per second. At a tip speed of 1644 feet per second, the air-flow range was extremely limited and a peak efficiency of 0.626 was obtained at a pressure ratio of 3.12. Mild surging of the unit was encountered at all pressure ratios above 3.0 for the equivalent tip speed of 1740 feet per second; the peak efficiency was 0.580 and the corresponding pressure ratio was 3.36.

4. The semivaneless diffuser appeared to be well matched with the mixed-flow impeller. The peak pressure ratios occurred at approximately equal values of volume flow for the semivaneless- and the vaneless-diffuser combinations. At low tip speeds, the peak efficiencies for both diffuser combinations occurred at approximately equal values of volume flow. At high tip speeds, the volume flows at which peak efficiencies were obtained differed for the two diffuser combinations but the difference in the values of peak efficiencies was small.

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3. NACA Subcommittee on Supercharger Compressors: Standard Method of Graphical Presentation of Centrifugal Compressor Performance. NACA ARR No. E5F13a, 1945.

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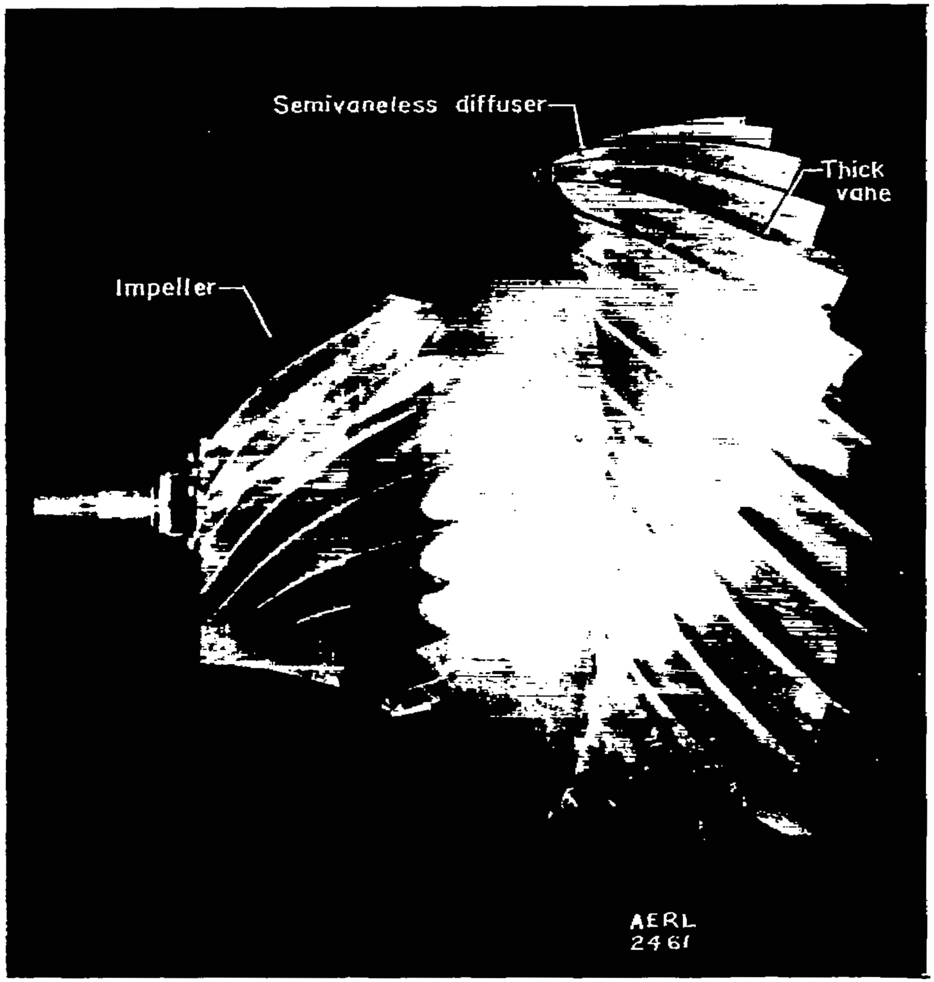

Figure 1. - Mixed-flow impeller and semivaneless diffuser with impeller and diffuser front shroud removed.

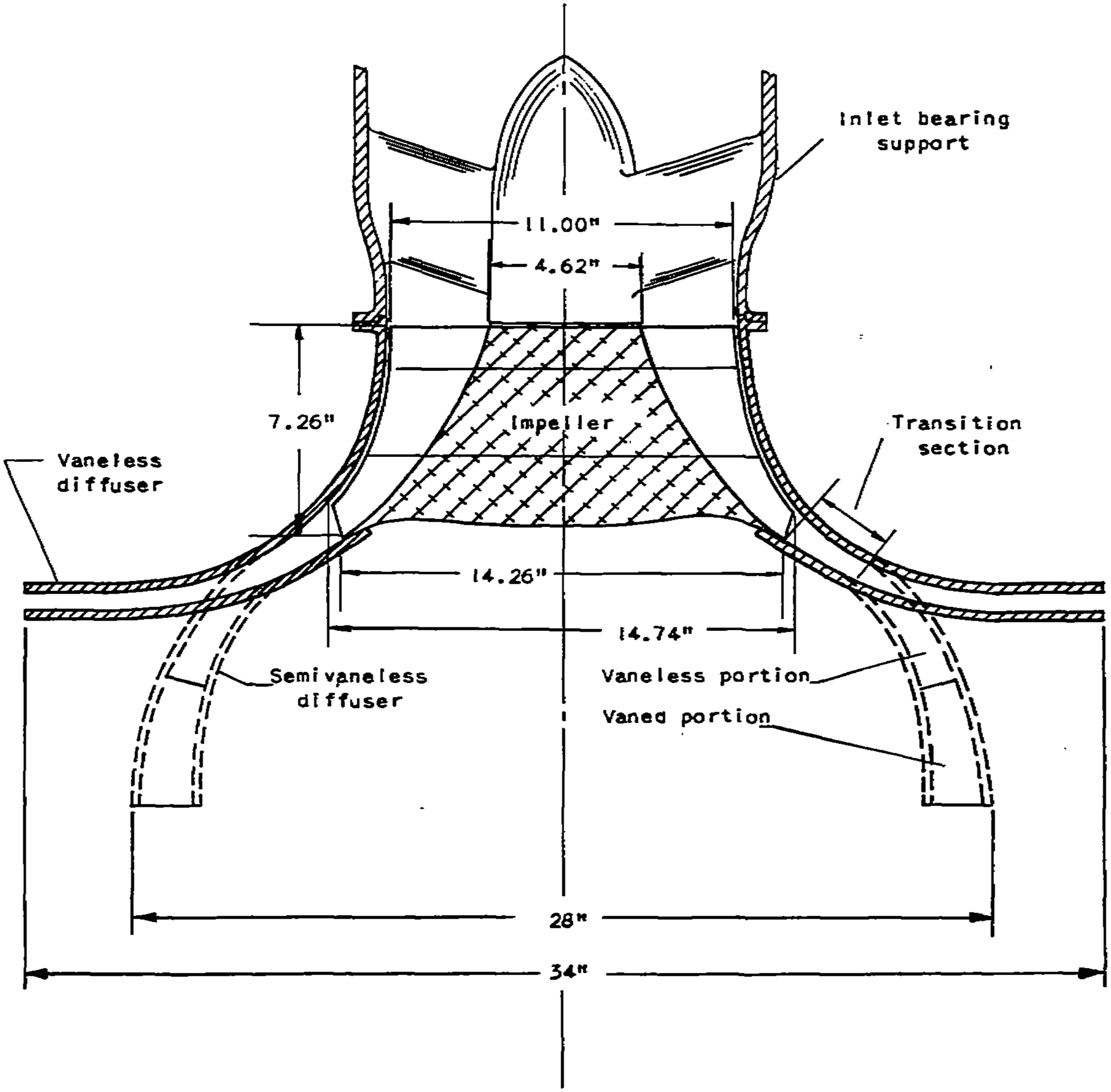

Figure 2. – Configurations of semivaneless and vaneless diffusers with mixed-flow impeller.

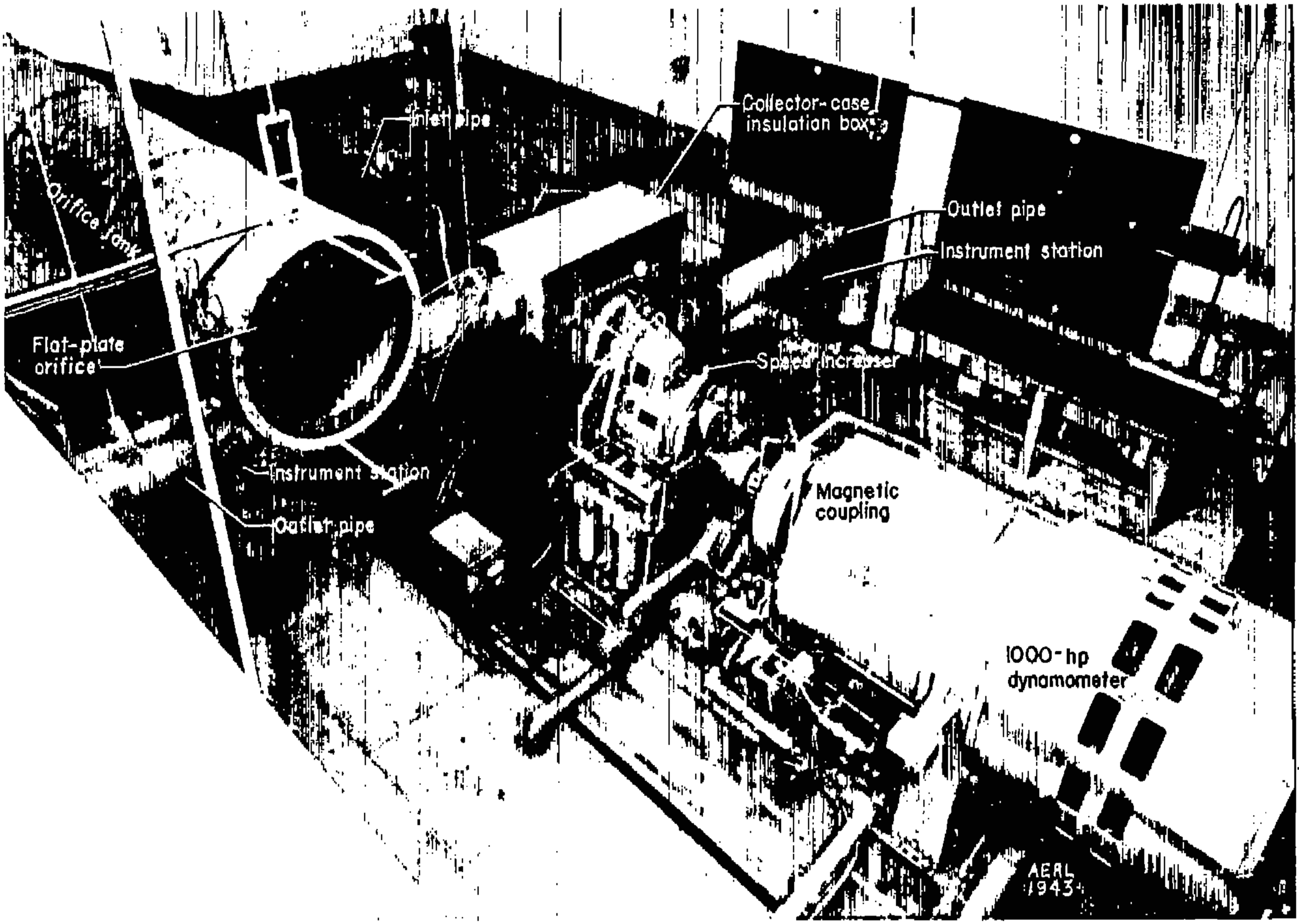

Figure 3. - Test setup for ambient-air tests

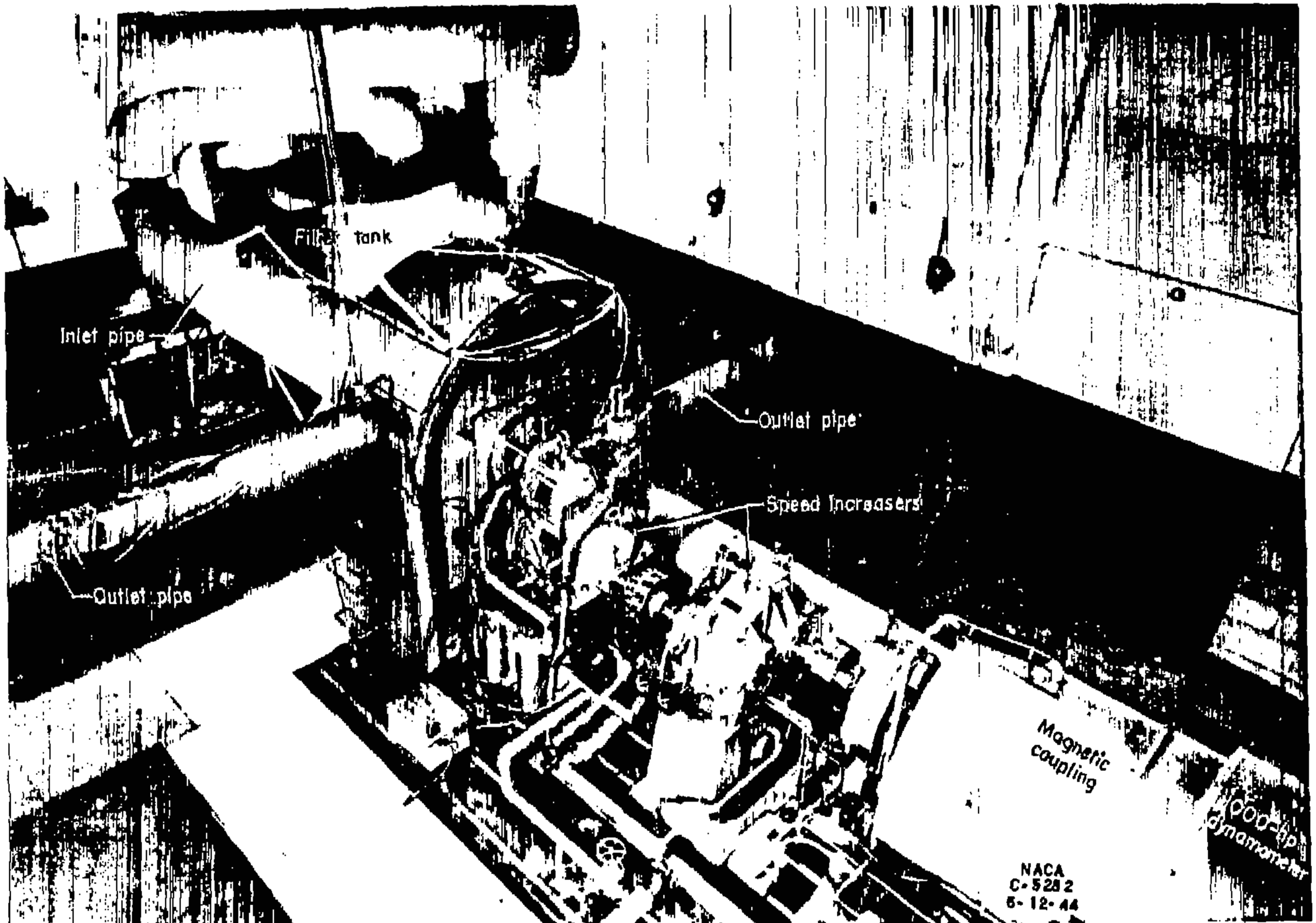

Figure 4. - Test setup for refrigerated-air tests.

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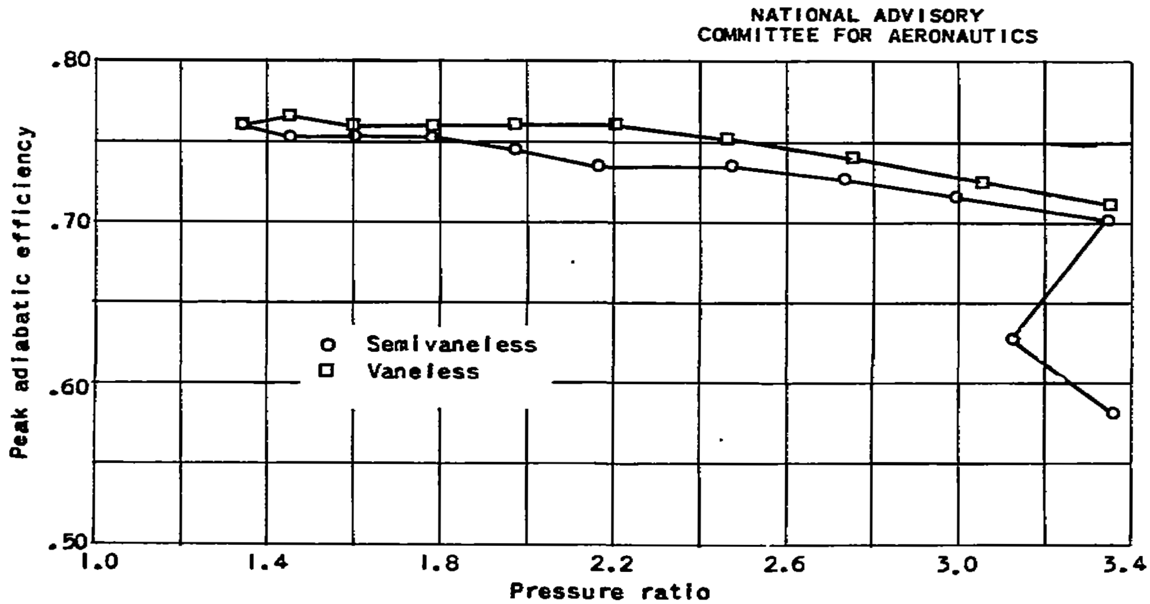
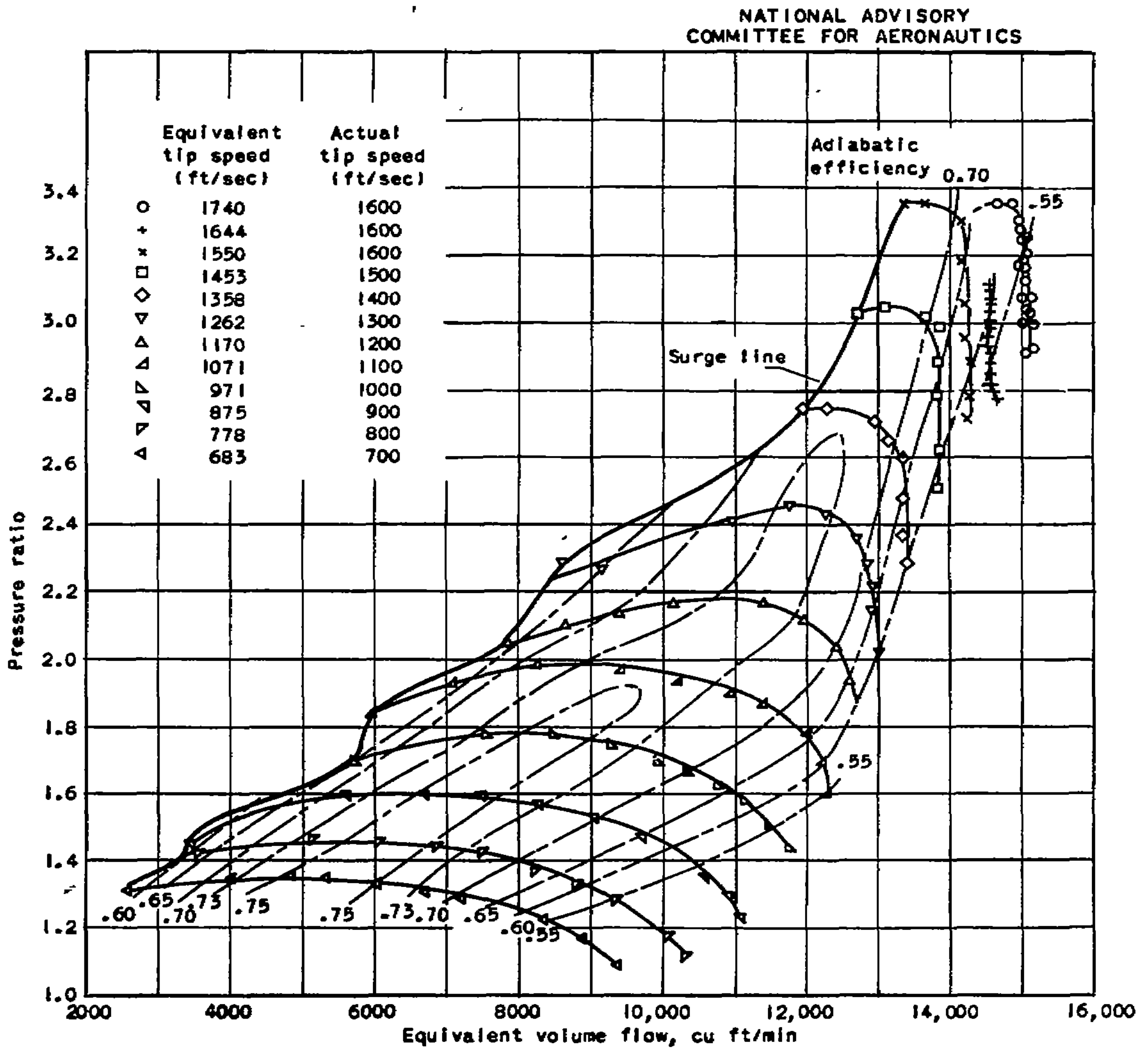
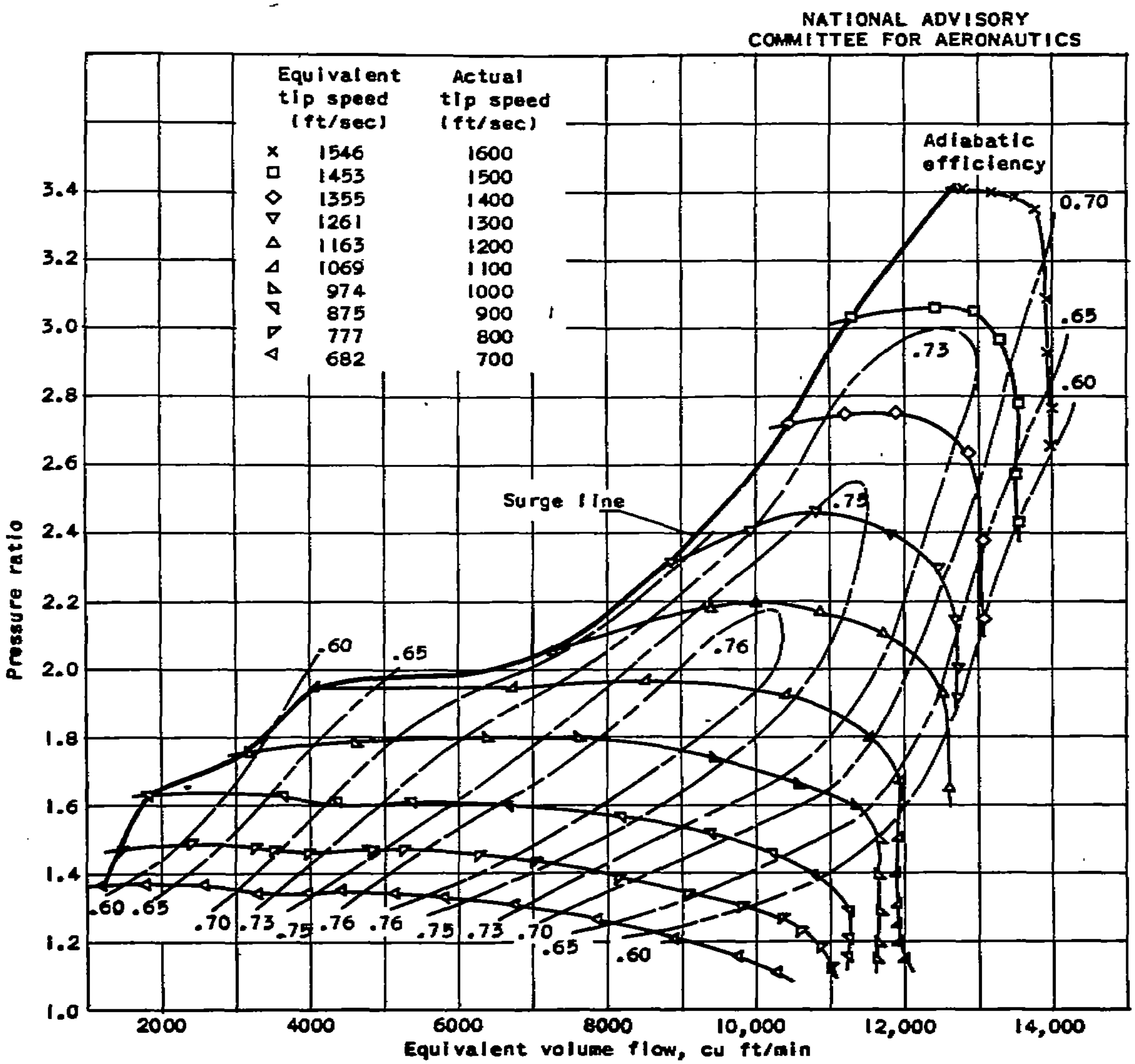


Figure 5. - Peak adiabatic efficiencies of semivaneless- and vaneless-diffuser combinations.



(a) Semivaneless diffuser.

Figure 6. – Performance of impeller-diffuser combinations.



(b) Vaneless diffuser.

Figure 6. - Concluded. Performance of impeller-diffuser combinations.

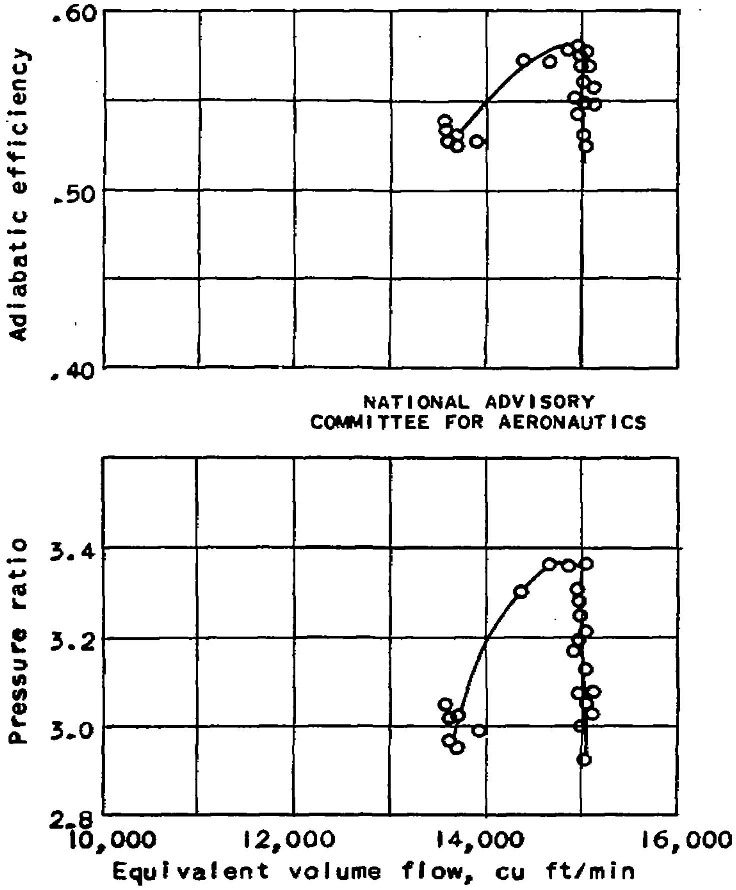
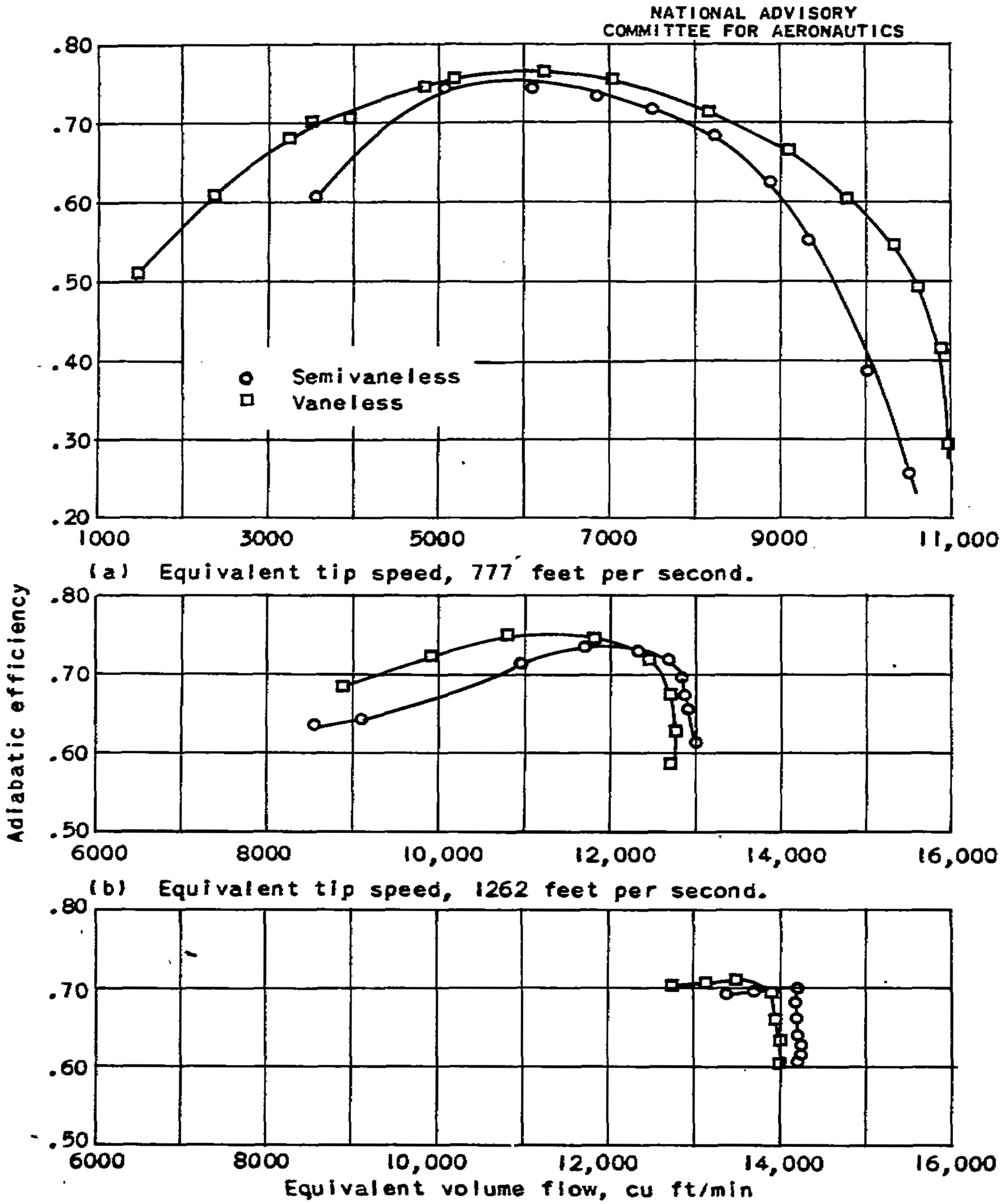


Figure 7. – Performance characteristics of semivaneless-diffuser combination at equivalent impeller tip speed of 1740 feet per second.



(c) Equivalent tip speed, 1548 feet per second.

Figure 8. - Comparative efficiency characteristics of semivaneless- and vaneless-diffuser combinations for tip speeds of 777, 1262, and 1548 feet per second.